Diatom nanostructured frustule: new insights for the design of novel biomimetic materials

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Diatoms are the most widespread creatures in all aquatic environments and among the most important from an ecological point of view. The hallmark of these nano-sized unicellular organisms, which for years has stimulated the interest of the scientific community and beyond, is their protective biosiliceous exoskeleton known as the frustule. The diatom frustule, in addition to being a wonderful and sophisticated threedimensional physical barrier, is an amazing example of how nature is able to produce multifunctional structures through the hierarchical assembly of a few simple constituents. Previous studies of diatoms have focused primarily on the role of their shells for filtration, drug delivery, biosensing, and scaffolding. Recently, there has been a growing interest in the mechanical properties of the frustule, with potential implications in nanotechnology and large-scale bioinspired structures. In this work, we investigate the role of nanomorphological features of diatoms on frustule mechanical properties and functionality via numerical finite element simulations and experimental tests, performed on 3D-printed diatom-inspired samples. In particular, we focus on the Coscinodiscus sp. and on the out-of-plane behavior of its multilayer shell. To simplify the study, we consider only the middle layer, characterized by a honeycomb-like structure, and we build several 3D geometric models to probe the effect of shape- and size-gradients on the overall out-of-plane mechanical behavior. The transfer of nature's design principles to engineering, and specifically the functional gradients and heterogeneities present in biological materials, can open new avenues towards increasing the efficiency and performance of man-made materials. Thus, this research may provide new insights for the design of novel biomimetic diatom-like materials and engineering device innovation based on multifunctional biological nanomaterials.